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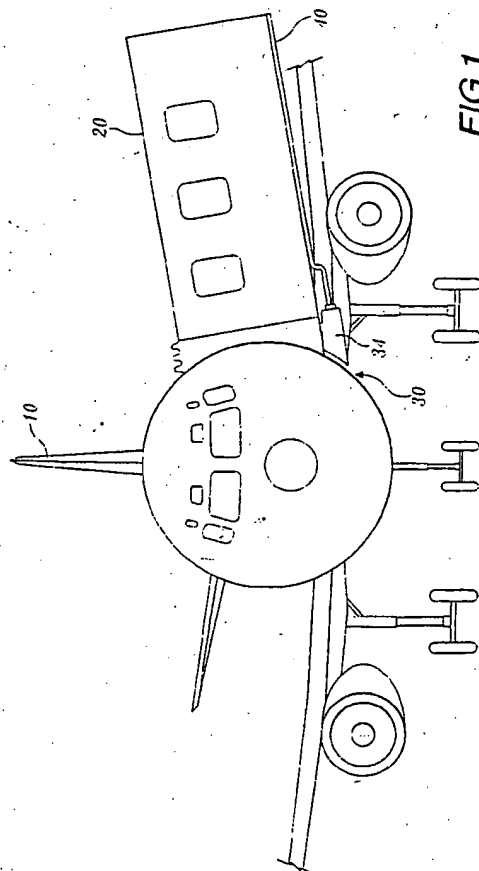
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(54) **Wide-angle, high-speed, free-space optical communications system.**

(57) A free-space optical communications system for transmitting data between an aircraft computer system (14) and a ground-based computer system (12). The system includes a pair of corresponding optical transmitters (36) and optical receivers (38) that transmit and receive optical signals transmitted between the two computer systems. Included within each optical transmitter is one or more light-emitting diodes (42) that produce optical signals corresponding to the data to be transmitted. A beam-forming prism (44) is bonded directly to the light-emitting diodes to direct the optical signal uniformly over a target area. The optical receiver includes one or more infrared windows (50) to reduce the amount of ambient light received by the optical receiver. A compound parabolic concentrator (64) collects light transmitted from the optical transmitter and directs the light onto an avalanche photodiode (66), which includes thermal bias compensation. An AC network couples the output signal of the photodiode to a transimpedance amplifier (70). An optional optical shroud (34) surrounds the optical transmitters and receivers to further reduce the amount of ambient light that is received by the optical receivers.



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## Field of the Invention

The present invention relates to communications systems in general and, in particular, to infrared, free-space optical communications systems.

## Background of the Invention

In the last 20 years, computers have played an ever increasing role in the airline industry. For example, computers are used onboard an aircraft for such tasks as aiding navigation, scheduling maintenance, monitoring the operation of equipment as well as for controlling the position of the flight control surfaces to fly the aircraft. On the ground, computers are used to ticket passengers, keep track of their luggage, maintain records of seat availability, schedule departure changes, etc. In the past, there has only been a limited exchange of data between the aircraft computer system and the ground-based computer system used by an airline. Such exchange usually took place by hand carrying a floppy disk between the two computer systems.

Since the invention of computer networks, there has been considerable effort within the airline industry devoted to developing a communication system that connects the aircraft computer system to the ground-based computer system. Early efforts used digital radio, but were unsuccessful because of the limited bandwidth available due to radio frequency spectrum allocation and contention/interference. One suggested method of establishing a higher bandwidth communication system was to connect the two computer systems together using a fiber optic communications link. In such a system, a fiber optic cable would extend from the ground-based computer system to a fiber optic cable connector disposed on the side of the aircraft. As the aircraft taxied into a dock, a member of the maintenance crew could plug the fiber optic cable into the side of the aircraft, thereby allowing the data communication to take place. However, such a solution was deemed undesirable due to the fragile nature of fiber optic cable connectors and the need for ground crew action. Additionally, it is possible that the aircraft could pull away from the dock without disconnecting the cable, causing subsequent delays and extensive damage to the fiber optic cable and aircraft.

To overcome the problems associated with a fiber optic cable-based communication system, an alternate communications scheme was suggested by the airlines industry. The alternate scheme involved the use of a free-space optical communications system that could transmit information between the aircraft computer system and the ground-based computer system using a modulated infrared light beam. The free-space optical communications system would eliminate the need for the fiber optic cable and the

possibility that damage might occur because the aircraft may pull away without disconnecting the cable. However, current free-space optical communications systems suffer from at least three problems that in combination prevent such communications systems from being readily usable in an aircraft to ground-based computer communication link. First, current free-space optical communications systems do not operate at the high data rate that the airlines are requiring for a commercially viable communication system. For example, the Aeronautical Radio Incorporated (ARINC) standards group is currently developing a communications protocol that requires data communication between an aircraft and a ground-based computer system be accomplished at speeds of 100 Mbits/sec. Second, current state of the art high-speed, free-space optical communications systems often have a narrow field of view and, as such, require additional control systems to align the optical transceivers to ensure proper data transmission. Including such control systems into a free-space optical communications system adds significantly to the cost of the system, as well as introduces a likely source of system failure. Finally, current free-space optical communications systems will not operate in all types of weather conditions experienced at an airport.

Therefore, a need exists for a free-space optical communications system that can transmit data between an aircraft and a ground-based system at high speeds over all weather conditions. Additionally, the communication system should have a wide field of view to eliminate the need for any control systems to align the optical components of the system.

## Summary of the Invention

The present invention comprises a free-space optical communications system that transmits data between two computer systems at high speed, in all weather conditions and without the need for precise alignment mechanisms. In the preferred embodiment of the present invention, the communication system is used to transmit information between an aircraft computer system and a ground-based computer system. The system includes a pair of optical transceivers, one of which is located on the aircraft and the other preferably located on an adjacent passenger loading bridge. Each transceiver includes an optical transmitter having one or more light-emitting diodes (LEDs) that produce optical signals corresponding to the data to be transmitted. Optically coupled to the LEDs is a nonimaging optical device such as a beam-forming prism to focus and uniformly distribute the optical signals over a target area in which the optical signals are to be received. Each transceiver also includes an optical receiver having one or more optical filters to reduce the amount of ambient light entering the receiver. A nonimaging optical collector such as a

compound parabolic concentrator (CPC) is coupled with the optical filters and collects a portion of the optical signals produced by the optical transmitter. The CPC is optically coupled to a photodiode, such as an avalanche photodiode (APD), which produces an electrical output signal that corresponds to the optical signals received. The APD diode includes a biasing voltage supply having temperature compensation and automatic gain control (AGC) to allow operation over a wide temperature and signal level range. A current shunt is connected to the output of the APD diode to shunt away a portion of the output signal that is produced due to any ambient light collected by the CPC. An AC coupling means extracts a time varying portion of the output signal and feeds the time varying portion to an amplifier. The output of the amplifier is coupled to the receiving computer system. An optional optical shroud extends between the adjacent passenger loading bridge and the aircraft to surround the pair of optical transceivers to reduce the amount of ambient light that is collected by the optical receivers.

#### Brief Description of the Drawings

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 shows a free-space optical communications system according to the present invention that transmits data between an aircraft computer system and a ground-based computer system;

FIGURE 2 shows an optional optical shroud that extends from a passenger loading bridge to the aircraft;

FIGURE 3 shows a block diagram of the free-space optical communications system according to the present invention;

FIGURE 4 shows an optical transmitter and an optical receiver according to the present invention; and

FIGURE 5 shows an optical window located on the side of the aircraft for transmitting and receiving optical communication signals.

#### Detailed Description of the Preferred Embodiment

The present invention is a duplex, free-space optical communications system for transmitting information between two computer systems. As discussed above, the preferred embodiment of the present invention is used to transmit information between an aircraft computer system and a ground-based computer system. However, the present system could also be used to transmit information between any two computer systems, stationary or mobile, such as an

automobile computer and a toll booth computer system, or from a computer system on a train to a ground-based computer system, etc.

FIGURE 1 shows an aircraft 10 parked near a passenger loading bridge 20. As will be further described below, the free-space optical communications system 30 according to the present invention allows data to be transmitted using infrared light beams that are transmitted between an optical transceiver located behind an infrared window disposed in the side of the aircraft and a corresponding optical transceiver located underneath a passenger loading bridge 20. The transceiver disposed on the underside of the passenger loading bridge 20 is coupled to the ground-based computer system via a communications cable 40 such as a fiber optic cable. In the preferred embodiment, the optical shroud 34 is mounted on the underside of the passenger loading bridge 20. The free-space optical communications system can transmit data between the aircraft computer system (not shown) and the ground-based computer system (also not shown) at a rate of 100 Mbits/sec. Additionally, as will be further described below, the free-space optical communications system according to the present invention has wide transmission beams and corresponding wide fields of view to compensate for misalignments between the aircraft 10 and the passenger loading bridge 20 and needs no active control mechanisms to align the optical transceivers.

FIGURE 2 shows how the free-space optical communications system according to the present invention is disposed underneath the passenger loading bridge 20 to transmit information between the aircraft computer system and the ground-based computer system. The optical shroud 34 extends between the passenger loading bridge 20 and the aircraft 10 to reduce the amount of ambient light that reaches the optical transceivers when the aircraft is parked at the passenger loading bridge. The optical shroud 34 has a horn-shaped construction with a cross-sectional area slightly larger than the transmitted beam from the transceiver disposed on the passenger loading bridge 20. The shroud 34 is approximately 1 meter long. Although the preferred embodiment of the present invention uses the optical shroud to reduce the amount of ambient light that enters the receivers, it will be apparent to those skilled in the art that such a shroud is not always required.

The communications cable 40 extends between the optical transceiver located under the passenger bridge 20 and the ground-based computer system (not shown) to carry the data to be transmitted by and the data received from the ground-based computer system.

As will be further discussed below, the optical transmitters transmit infrared optical signals uniformly over large target areas. Correspondingly, the optical receivers have large fields of view. This ensures that

data communication can take place regardless of where in the target area a corresponding transceiver is located due to misalignment of the transceivers.

The size of the open end of shroud 34 at the point where the shroud nears the aircraft is large enough so that it does not interfere with the target area on the aircraft. In the preferred embodiment, the aircraft transceiver includes an infrared window 50 that covers the transceiver and is located flush with the surface of the aircraft 10 in a position that is generally below a door 17. When the aircraft is properly docked next to the passenger loading bridge 20, the infrared window 50 will be located within the respective target area.

A block diagram of the free-space optical communications system according to the present invention is shown in FIGURE 3. The free-space optical communications system 30 transmits data bi-directionally between a ground-based computer system 12 and an aircraft computer system 14. The system includes a pair of optical transceivers each of which includes a separate optical transmitter 36 and an optical receiver 38. The optical shroud 34 reduces the amount of ambient light that is received by the optical receivers 38. To further reduce the amount of ambient light that enters the optical receivers 38, the transceivers include a pair of infrared windows 50. Data is transmitted between the two computer systems 12 and 14 via a modulated infrared light beam produced by the optical transmitters 36. Each optical transceiver is coupled to its respective computer system via a communications cable 40. In the preferred embodiment of the present invention, data is transmitted in full duplex between the ground-based computer system 12 and the aircraft computer system 14.

A more detailed view of the optical transmitter 36 and the optical receiver 38 is shown in FIGURE 4. For purposes of illustration, FIGURE 4 shows one optical transmitter 36 and a corresponding optical receiver 38. However, as will be appreciated, the system includes a second optical transmitter and corresponding optical receiver to transmit data in the opposite direction. The optical transmitter 36 includes a plurality of infrared light emitting diodes (LEDs) 42 driven by a transistor 43. An electronic signal that corresponds to the data to be transmitted is applied to the base electrode of the transistor 43, causing the transistor 43 to conduct current and in turn causing the plurality of LEDs 42 to produce an infrared optical signal. In the present embodiment, the LEDs 42 comprise a two-by-two array of infrared LEDs connected in series to increase the optical power of the infrared signals produced.

Because the infrared light produced by the plurality of LEDs 42 extends at wide angles from the face of the LEDs, a beam-forming dielectric prism 44 is optically coupled to the face of the LEDs 42. As a result, the beam-forming prism 44 collects the infrared

light and directs it towards the corresponding optical receiver 38. The beam-forming prism is made of any type of transparent optical material, including plastic or glass. The dimensions of the prism are chosen depending on the size of the target area and the separation between the transceivers. The beam-forming prism should take into account the illumination pattern of the LEDs and the difference in the index of refraction between the material that comprises the prism and the surrounding air so that infrared light produced by the plurality of LEDs 42 is directed with equal intensity over the entire target area. The angles of the sides of the prism are approximately equal to the angles of the optical beam required to cover the target area. The design parameters are defined to optimize optical intensity in the target area.

The beam-forming prism 44 increases the optical power that is transmitted in the direction of the receiver as well as distributes the optical signals evenly over the target area. As described above, the target area is a rectangular section. The size of the target area compensates for variations or misalignments between the aircraft and the passenger loading bridge. If the aircraft is parked such that the corresponding optical receiver 38 is located anywhere in the target area, then communication can take place between the aircraft and ground-based computers.

Disposed at the output end of the beam-forming prism 44 is an infrared window 50a. The infrared window 50a passes light having frequencies in the infrared range and serves to protect the optical transmitter from dirt, rain, etc.

The optical receiver 38 includes an infrared window 50b that preferably only passes light having frequencies in the infrared range of the optical transmitter 36. Disposed directly behind the infrared window 50b is a cylindrical lens 60. The cylindrical lens 60 serves to modify a circular field of view of a compound parabolic concentrator 64 into an elliptical field of view, where a noncircular field of view is needed. The cylindrical lens 60 therefore increases the light that is detected by receiver 38 in one axis.

Infrared light travelling through the infrared window 50b and the cylindrical lens 60 is collected by the dielectric, compound parabolic concentrator (CPC) 64. The CPC 64 is optically coupled to the light-sensitive surface of a photodiode 66. Preferably, the photodiode 66 is an avalanche photo detector (APD) type that conducts an electrical current that is proportional to the level of light received, however, other types of photo detectors could be used such as a PIN photodiode. The CPC 64 has superior light-gathering properties as compared to the imaging lens typically used with optical detectors. The CPC has a large far field of view and in combination with the cylindrical lens 60 can receive light from anywhere in the target area with high efficiency. The design parameters of the CPC are chosen to maximize the optical power

detected in the target area. This large field of view is also sharply defined such that any light outside the field of view is not directed to the APD diode 66. This property also helps reduce the amount of ambient light received by the diode. Finally, the light-gathering properties of the CPC are nearly uniform across its field of view. Therefore, there are no "dead spots" within the CPC's field of view that would attenuate any optical signal detected. The CPC 64 is preferably made of a dielectric material bonded directly to the light-gathering surface of the APD diode 66 with an optical grade epoxy. The details of how to construct a compound parabolic concentrator are well known to those skilled in the optical arts and therefore will not be discussed further.

The APD diode 66 is biased with a temperature compensated high voltage source 68 that produces photo current gain that does not substantially vary over wide temperature ranges. Disposed between the high voltage source 68 and the APD diode 66 is a resistor  $R_1$  and a capacitor  $C_1$ . The resistor  $R_1$  acts to provide automatic gain control for the optical receiver 38 as follows. In general, the electrical current that is generated by an APD diode 66 for a given amount of light increases exponentially as the bias voltage increases. However, as the APD diode 66 in the receiver 38 conducts more and more current due to more light being received, the voltage drop across the resistor  $R_1$  increases thereby reducing the voltage that biases the APD diode 66, causing the APD diode to conduct less current. This negative feedback action tends to maintain the level of current that is conducted by the APD diode relatively constant despite fluctuations in the amount of input light received, thereby preventing the APD diode from saturating and keeping the output signal produced by the APD diode relatively uniform in magnitude. The capacitor  $C_1$  operates in conjunction with the resistor  $R_1$  such that the negative feedback is determined by slow or average variations of the received optical signal strength.

The temperature compensation provided by the high voltage source 68 is accomplished by comparing a fixed fraction of the bias voltage applied to the APD diode to a reference voltage produced by an IC temperature sensor (not shown) within the high voltage source 68. The difference between these two voltages drives a high-gain, negative feedback circuit that includes a fixed gain DC to DC converter (also not shown) so that the bias voltage adjusts over temperature to maintain constant APD current gain.

Connected between the output of the APD diode 66 and ground or other reference potential is a resistor  $R_2$ . Although the optical shroud 34 and the infrared window 50b remove most of the ambient light that may be impinging upon the APD diode 66, it is inevitable that some ambient light will be collected by the CPC 64 and be passed to the APD diode. A coupling

capacitor  $C_2$  is connected between the output of APD diode 66 and a transimpedance amplifier 70. The capacitor  $C_2$  passes only a time-varying portion of the output signal to the amplifier whereas current conducted by the diode 66 due to the ambient light is shunted to ground by resistor  $R_2$ . The time-varying portion of the output signal is directly proportional to the power of the optical signals produced by the optical transmitter 36 and received by the APD diode 66.

The transimpedance amplifier 70 with appropriate additional circuitry (not shown) converts an AC current flowing through the capacitor  $C_2$  into a digital voltage signal that is transmitted to either the aircraft computer system 14 or the ground-based computer system depending on whether the optical receiver 38 is located on the aircraft or on the ground.

As stated above, the free-space communications system according to the present invention also includes another optical transmitter and another optical receiver that transmit and receive data in the reverse direction. Together, these pairs of corresponding optical transmitters and receivers allow full duplex communication to take place between the aircraft computer system and the ground-based computer system. In operation, it is not necessary to vary the frequency of the optical signals that are transmitted from the aircraft to the ground-based computer system with respect to the frequency of the optical signals that are transmitted from the ground-based computer system to the aircraft. Full duplex transmission can take place if precautions are taken to ensure that the optical signals transmitted by a transceiver's optical transmitter are not received by the transceiver's own optical receiver. This is accomplished in the present invention by splitting each transceiver's window into two halves 50a and 50b as shown and discussed in further detail below.

FIGURE 5 shows an infrared window 50 disposed on the exterior surface of an aircraft 10. The window includes two separate infrared windows 50a and 50b similar to those shown in FIGURE 4. The window is mounted flush with the outer surface of the aircraft 10. A divider 55 separates the two infrared windows 50a and 50b to prevent light transmitted from the beam-forming prism 44 from leaking into the cylindrical lens 60. By preventing such leakage or cross-talk, the communication system according to the present invention can operate in full duplex at high data rates using the same frequency light pulses for data transmission in both directions.

As will be appreciated, the communication system according to the present invention is "passive" in the sense that no special equipment is needed to align the optical transceivers. This has the benefit of not only being cheaper to manufacture but is also less likely to malfunction as the communication system is exposed to the environment.

While the preferred embodiment of the invention

has been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.

### Claims

1. A free-space optical communications system for transmitting data between an aircraft computer system and a ground-based computer system, comprising:
  - an optical transmitter for producing optical signals that correspond to the data to be transmitted between the aircraft computer system and the ground-based computer system, wherein the optical transmitter includes:
    - (a) light-producing means for producing optical signals corresponding to the data to be transmitted;
    - (b) light-directing means for gathering the optical signals produced by the light-producing means and for distributing the optical signals uniformly over a target area;
  - an optical receiver for the optical signals produced by the optical transmitter, wherein the optical receiver includes:
    - (a) optoelectronic means for producing an output signal that corresponds to the data transmitted;
    - (b) light-gathering means for gathering a portion of the optical signals produced by the light-producing means and for directing the portion of the optical signals gathered to the optoelectronic means; and
    - (c) light-filtering means for reducing the amount of ambient light directed to the optoelectronic means.
2. The free-space optical communications system of Claim 1, further comprising:
  - an optical shroud that extends between the optical transmitter and the optical receiver for reducing the amount of ambient light that is received by the receivers.
3. The free-space optical communications system of Claim 1, wherein the optical receiver further includes means for removing a portion of the output signal due to ambient light received by the optical receiver.
4. The free-space optical communications system of Claim 1, further comprising:
  - gain control means for regulating the magnitude of the output signal produced by the optoelectronic means.

5. The free-space optical communications system of Claim 1, further including:
  - a temperature-compensated biasing means for providing a bias voltage to the optoelectronic means.
6. The free-space optical communications system of Claim 1, wherein the light-gathering means for gathering a portion of the optical signals comprises a compound parabolic concentrator that is bonded directly to the optoelectronic means.
7. A free-space optical communications system for transmitting data bi-directionally between an aircraft computer system and a ground-based computer system, comprising:
  - an optical transmitter that includes:
    - (a) one or more light-emitting diodes (LEDs) that produce optical signals corresponding to the data to be transmitted between the aircraft computer system and the ground-based computer system;
    - (b) a beam-forming prism optically coupled to one or more LEDs to collect the optical signals produced by the one or more LEDs and direct the optical signals toward a corresponding optical receiver; and
  - an optical receiver that receives the optical signals transmitted from the optical transmitter, wherein the optical receiver includes:
    - (a) an avalanche photodiode (APD diode) that produces an output signal that is proportional to a received optical signal;
    - (b) a compound parabolic concentrator bonded to the APD diode that collects the optical signals transmitted from the optical transmitter and directs the optical signals onto the APD diode;
    - (c) current shunt means coupled to an output of the APD for shunting away a portion of the output signal that is due to ambient light collected by the compound parabolic concentrator; and
  - shroud means for surrounding the first and second transceivers to reduce the amount of ambient light received on the optical receivers.
8. The free-space optical communications system of Claim 7, wherein the optical receiver further includes:
  - an optical filter disposed between the corresponding optical transmitter and the APD diode.
9. The free-space optical communications system of Claim 7, wherein the optical receiver further comprises:
  - a temperature-compensated voltage sup-

ply that provides a temperature-compensated biasing voltage to the APD diode.

10. The free-space optical communications system of Claim 7, wherein the optical receiver further comprises:

means for extracting a time varying portion of the output signal produced by the APD diode.

11. A free-space optical communications system for transmitting data between an aircraft computer system and a ground-based computer system comprising:

a pair of optical transmitters, one of which is coupled to the aircraft computer system and another of which is coupled to the ground-based computer system, wherein each of the optical transmitters includes:

(a) one or more light-emitting diodes (LEDs) that produce optical signals that correspond to data to be transmitted;

(b) a beam-forming prism optically coupled to one or more LEDs for uniformly distributing optical signals produced by the LEDs over a target area, and

a pair of optical receivers, one of which is coupled to the aircraft computer system and another of which is coupled to the ground-based computer system, wherein each optical receiver includes:

(a) light-collecting means for gathering light that impinges upon the optic receiver;

(b) a photodiode bonded to the light-collecting means, the photodiode producing an electrical signal that is proportional to the amount of light gathered by the light-collecting means; and

(c) filter means for reducing the amount of ambient light received by the photodiode.

12. The free space, optical communications system of Claim 11, further comprising:

an optical shroud disposed around the optical transmitters and optical receivers that reduces the amount of ambient light received by the optical receivers.

13. A method of optically transmitting data between an aircraft computer system and a ground-based computer system, comprising the steps of:

producing an infrared optical signal that corresponds to the data to be transmitted;

directing the infrared optical signal towards an optical receiver;

gathering light at the optical receiver;

filtering the gathered light to remove light that has a frequency outside of an infrared frequency range;

directing the filtered light onto a photodiode that produces an electrical signal that is proportional to the amount of infrared light directed onto said photodiode;

removing a component of the electrical signal produced by the photodiode due to ambient light received by the optical receiver; and

coupling an AC component of the electrical signal produced by the photodiode to an amplifier, wherein the AC component of the electrical signal is proportional to the data transmitted between the aircraft computer system and the ground-based computer system.

14. An optical transceiver disposed on an aircraft for transmitting data between an aircraft computer system and a ground-based computer system comprising:

an optical transmitter for producing optical signals that correspond to data to be transmitted between the aircraft computer system and the ground-based computer system, including:

(a) one or more light-emitting diodes coupled to the aircraft computer system for producing the optical signals;

(b) a beam-forming prism optically coupled to the one or more light-emitting diodes for gathering the optical signals and distributing the optical signals uniformly;

an optical receiver for receiving optical signals, including:

(a) a photodiode coupled to the aircraft computer system, the photodiode producing an output signal that is proportional to a received optical signal;

(b) light-collecting means bonded to the photodiode that collects optical signals and directs the collected optical signals onto the photodiode;

(c) a current shunt coupled to the output signal produced by the photodiode that shunts a portion of the output signal due to ambient light collected by the light-collecting means; and

(d) an optical filter disposed in front of the light-collecting means that reduces the amount of ambient light received by the light-collecting means.

15. An optical communications system for transmitting data between a first computer system and a second computer system, comprising:

an optical transmitter for producing optical signals that correspond to the data to be transmitted between the first computer system and the second computer system, wherein the optical transmitter includes:

(a) light-producing means for producing optical signals corresponding to the data to be transmitted;

(b) light-directing means for gathering the optical signals produced by the light-producing means and for distributing the optical signals uniformly over a target area;

an optical receiver for the optical signals produced by the optical transmitter, wherein the optical receiver includes:

(a) optoelectronic means for producing an output signal that corresponds to the data transmitted;

(b) light-gathering means for gathering a portion of the optical signals produced by the light-producing means and for directing the portion of the optical signals gathered to the optoelectronic means; and

(c) light-filtering means for reducing the amount of ambient light directed to the optoelectronic means.

16. The optical communications system of Claim 15, wherein the optical receiver further includes means for removing a portion of the output signal due to ambient light received by the optical receiver.

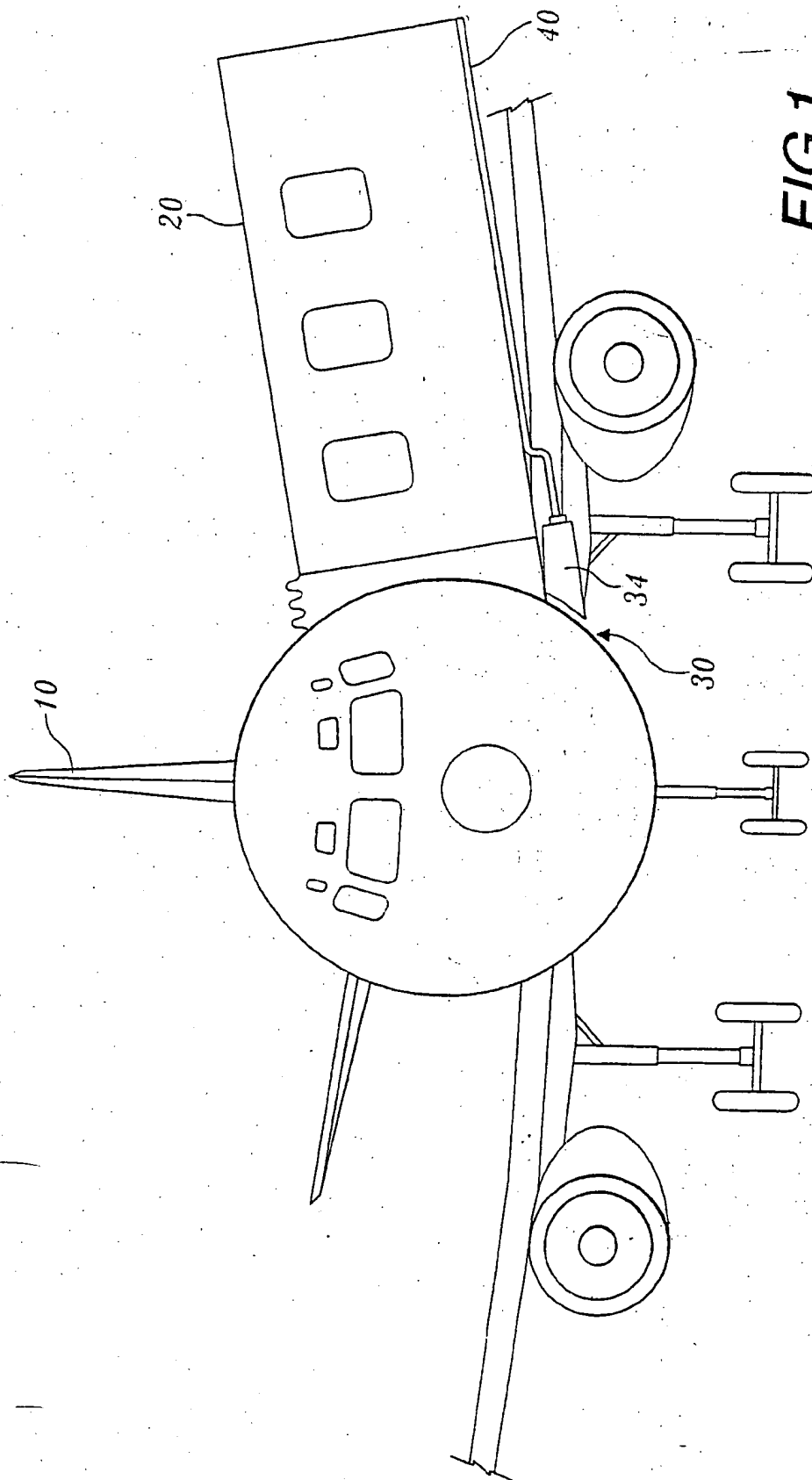
17. The optical communications system of Claim 15, further comprising:  
gain control means for regulating the magnitude of the output signal produced by the optoelectronic means.

18. The optical communications system of Claim 15, further including:  
a temperature-compensated biasing means for providing a bias voltage to the optoelectronic means.

19. The optical communications system of Claim 15, wherein the light-gathering means for gathering a portion of the optical signals comprises a compound parabolic concentrator that is bonded directly to the optoelectronic means.

20. The optical communications system of Claim 15, wherein the light-directing means comprises a beam-forming prism optically coupled to the light-producing means.





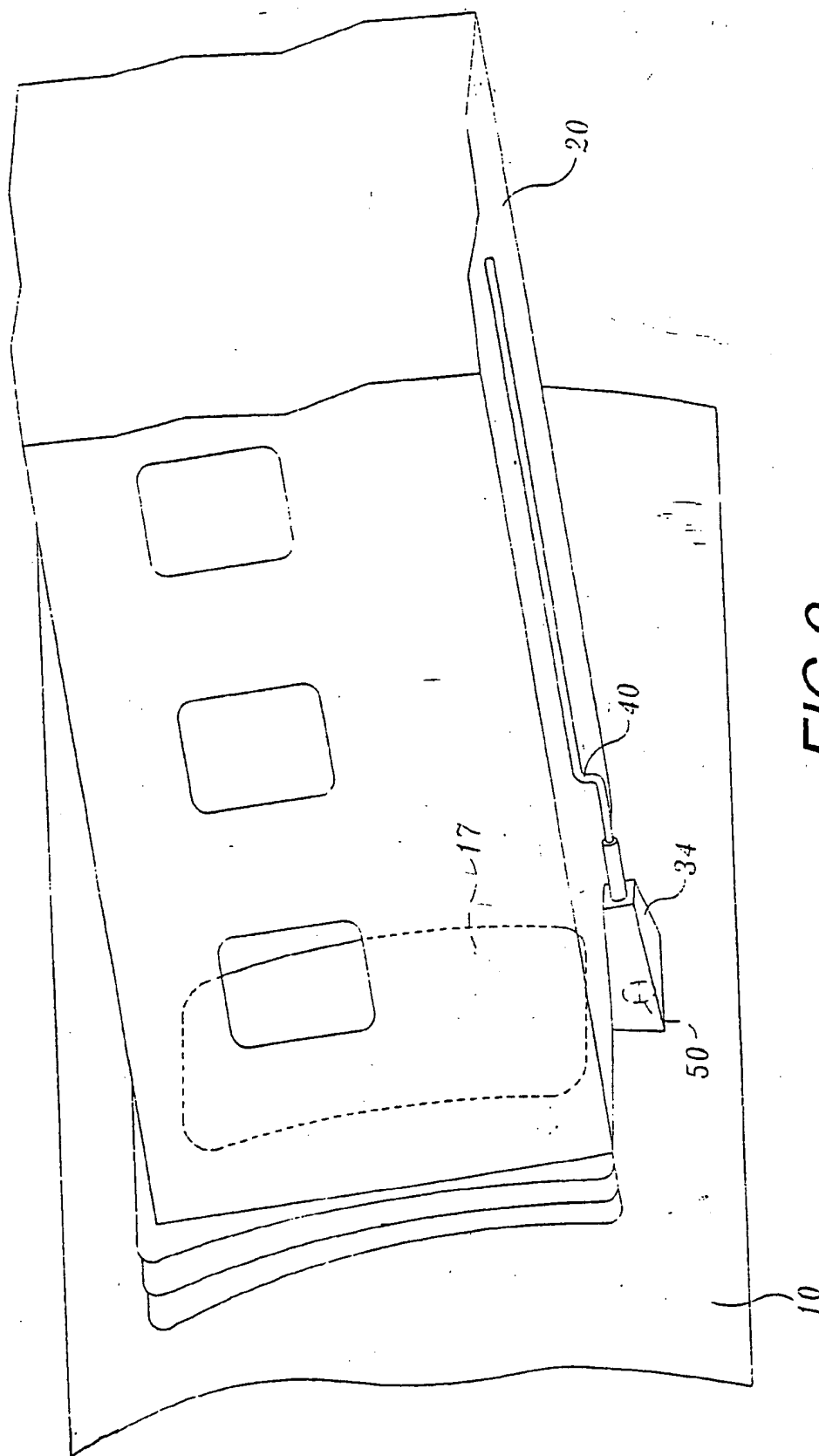


FIG. 2.

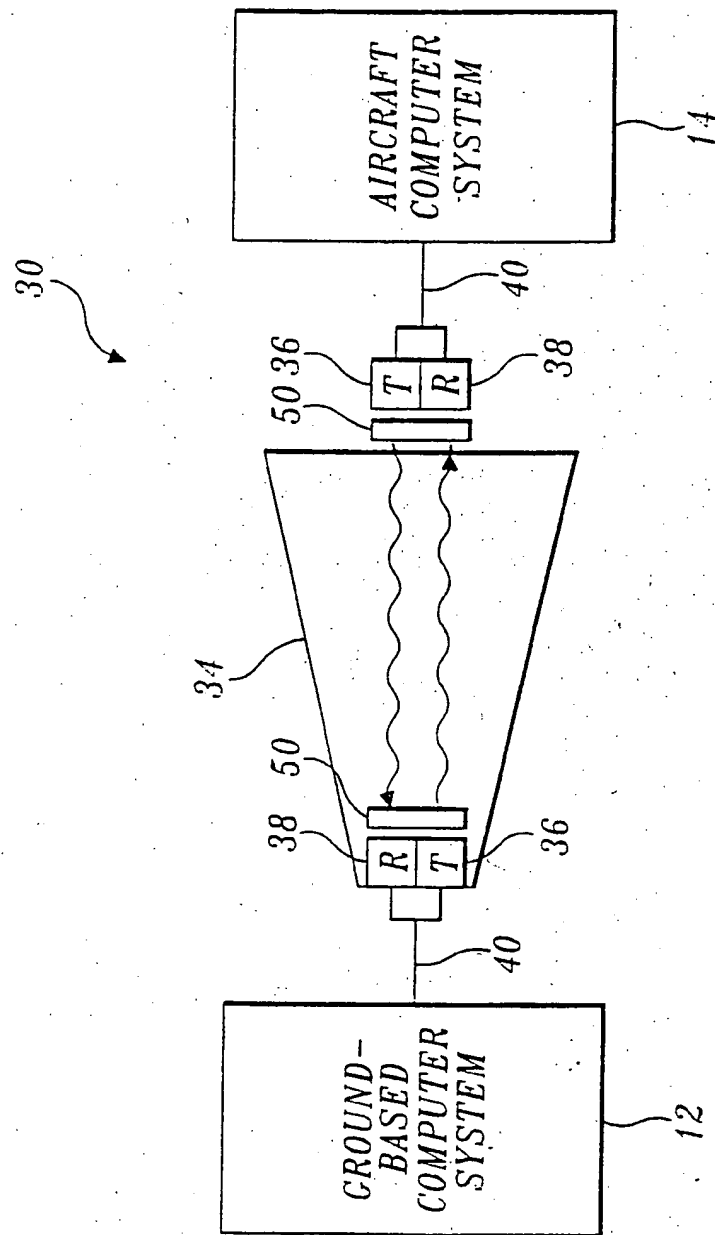


FIG.3.

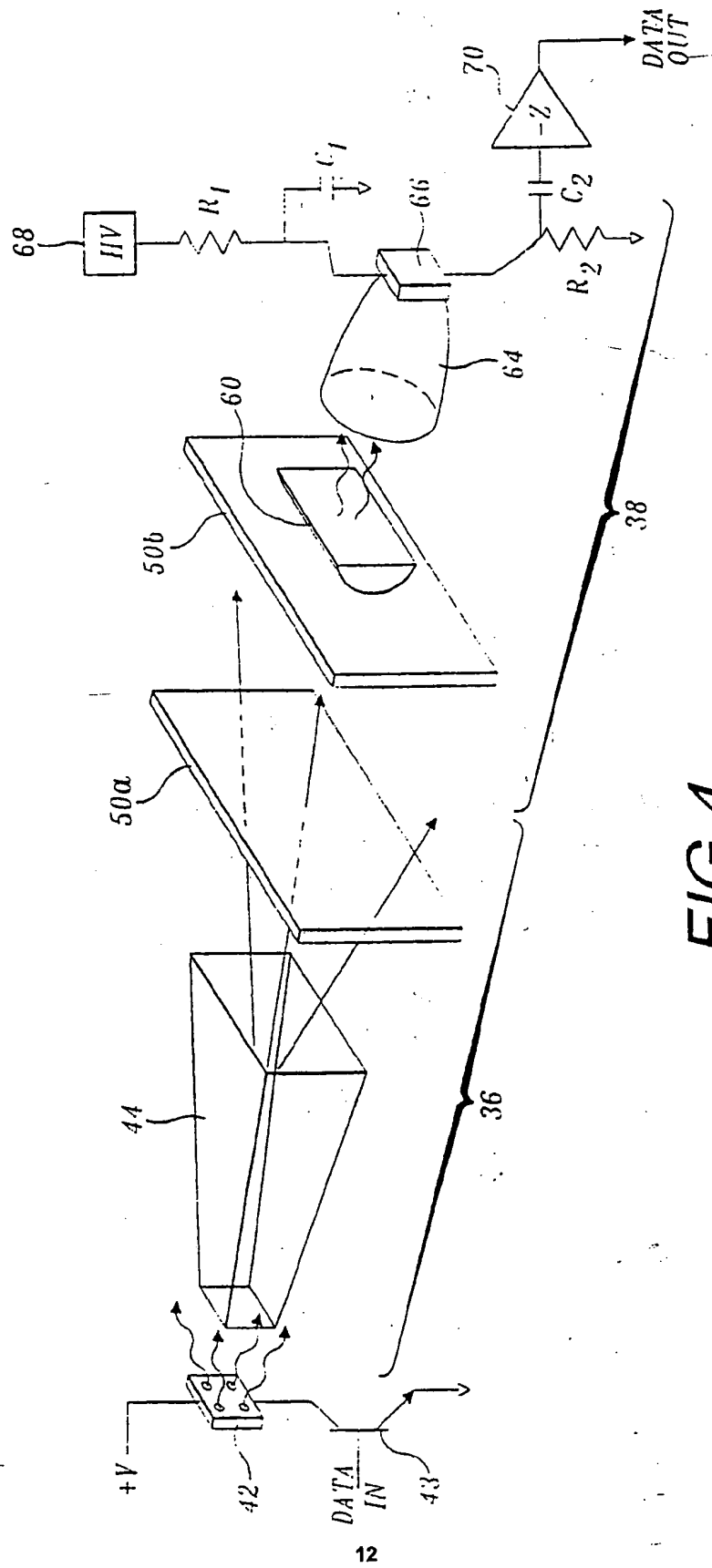


FIG. 4.

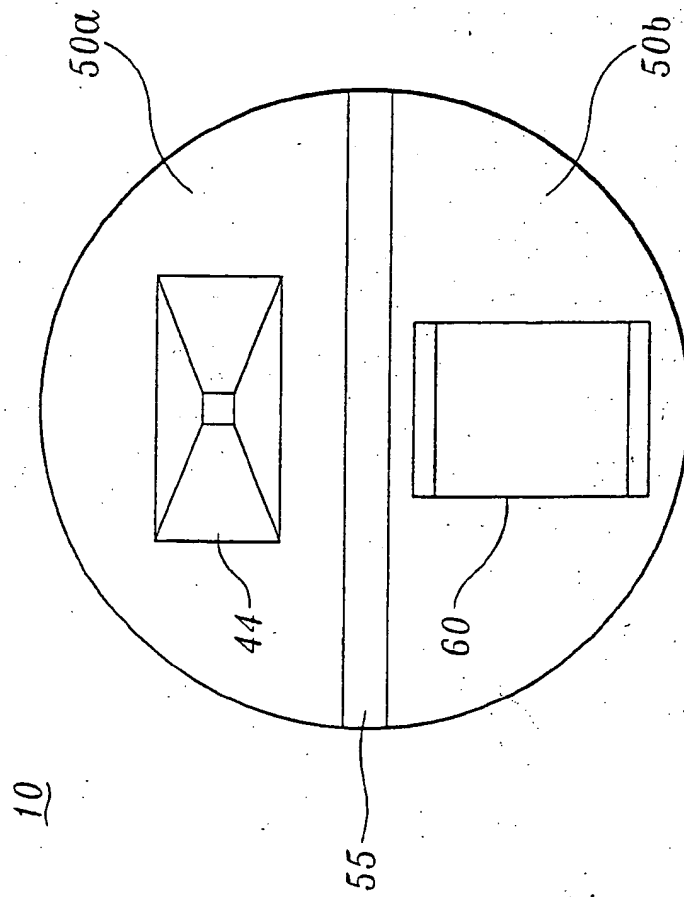


FIG. 5.



European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number  
EP 93 30 6926

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	GB-A-2 228 385 (ANALYTICAL INSTRUMENTS)  * page 4, line 20 - page 5, line 6 * * page 6, line 2 - line 10 * * page 6, line 16 - page 7, line 1 * * page 11, line 1 - line 7 * * page 12, line 5 - line 13 * * claims 1,3-9 *	1,7,11, 13-15	H04B10/10
A	WO-A-90 03072 (WILMOTH)  * page 1, line 14 - line 15 * * page 5, line 29 - page 6, line 6 * * page 6, line 16 - line 21 * * page 6, line 32 - page 7, line 3 * * page 8, line 2 - line 7 * * figures 3,5,7 *	1,2,7, 11-15	
A	DE-A-30 08 700 (DORNIER)  * claim 1 *	1,7,11, 13,14	TECHNICAL FIELDS SEARCHED (Int.Cl.5)  H04B
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>13 December 1993</b>	Examiner <b>Williams, M</b>
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone V : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application I : document cited for other reasons & : member of the same patent family, corresponding document			

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